Challenges of Creating Complex Integrated Vehicle System Models

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Overview

- Introduction / background
- System modeling process description
- Application examples including:
  - Powerplant subsystem
  - Transmission subsystem
  - Vehicle system control
  - Real-time simulation
- Conclusions

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System Modeling & Simulation

- Scope: time varying response, behavior and interactions of components in the context of a vehicle system
- Purpose: Understand/improve system performance before it is built
- Models include control algorithm logic and mathematical representations of selected component physical behaviors

Model Based Development for Vehicle Systems

- Model-based development (MBD) processes are essential for engineering complex vehicle systems
- For HEV systems, a critical element of MBD processes is the use of vehicle system models representing the key functional behaviors.
- Time and modeling resources are limited:
  - Maximizing model re-use is critical
  - Available subsystem/component models from across the Ford organization and brands (JLR, Volvo, Mazda) must be leveraged
  - Models to be re-used are implemented in variety of tools/environments
  - Integration into a robust, accurate functional model of the HEV system presents a number of challenges

System Modeling Process

Project Stage: Concept definition → Requirements & targets → Algorithm design & verification → HIL Validation → Vehicle Integration & Calibration

Ongoing Activities: *Attribute assessments (Performance, FE, Drivability)*

Different Vehicle Model Architecture Configurations

System Model:

Base Low Fidelity Model	Enhanced Low Fidelity Model	Medium Fidelity Model	HIL Model	Integrated System Model	High Fidelity Model

Model plug & play

Component Models:

- Base Low Fidelity Model
  - Std conventional models
  - Lo-fi component models of new technologies
- Enhanced Low Fidelity Model
  - Simple algorithm models
  - Enhanced lo-fi component models
- Medium Fidelity Model
  - Detailed algorithm models
  - Improved fidelity component models
- HIL Model
  - HIL compatible component models
  - Interfaces for HIL
- Integrated System Model
  - Algorithm models for key interacting systems
  - Improved fidelity component models
- High Fidelity Model
  - Highest fidelity component models
  - Software in loop

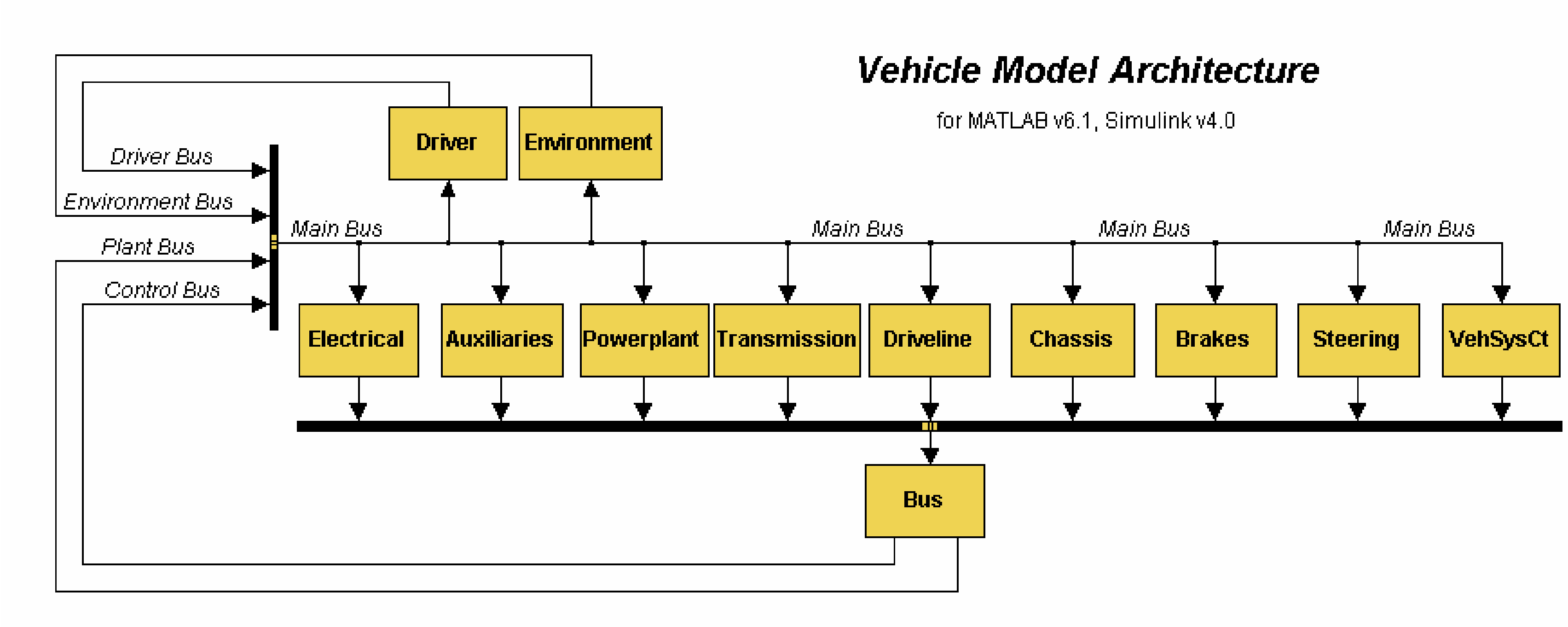
Model Library Enhancements

Model Development Process

- The Vehicle System Modeling (VSM) Process has been deployed at Ford to provide high quality, application appropriate vehicle system models in time to support critical HEV program engineering activities.
- This process involves:
  - Definition of vehicle-level, subsystem-level, and component-level model requirements for a specific modeling application
  - Collection of component and subsystem models and data from various sources
  - Integration of model elements from various sources in different toolsets
  - Parameterization of system model

Vehicle Model Architecture

- Well defined model structure that facilitates model re-use and sharing and reduces model development time and cost
- High-level modular structure for dynamic vehicle modeling
- Key vehicle subsystems are represented as distinct elements
- Subsystem connections specified through well-defined interfaces
- Structure & interface are fixed, model content is not



Model Integration

- When possible, component and subsystem models are acquired from other groups to maximize model re-use and minimize duplication of effort
- Component models are only created if appropriate models do not already exist
- These component models come in a variety of tool sets including but not limited to:
  - Commercial tools e.g. Dymola, AMESim, GT-Power, WAVE
  - Ford proprietary tools such as Ford Transmission Simulation Environment (FTSE)
- Integration of models into Simulink® from these varied environments poses many challenges including:
  - MATLAB® and Simulink® version compatibility
  - Variable vs. fixed step simulation
  - Folder structure and path dependence of support files
  - Different initialization scripts and masking methods

Dymola is a product of Dynasim AB; AMESim a product of IMAGINE SA; GT-Power a product of Gamma Technologies Inc; Wave a product of Ricardo Inc

Engine Plant Modeling

- Mean-value models:
  - Are useful for basic control algorithm development
  - Represent cycle-average dynamics and capture the primary transient response
  - Use tables or mathematical regressions developed from steady-state engine mapping data to predict engine states associated with in-cylinder processes
  - Can be implemented with little difficulty in native Simulink
- Crank-angle based engine models:
  - Are useful for in-depth investigation of key transient behaviors
  - These models represent:
    - 1-D intake and exhaust gas dynamics
    - In-cylinder thermodynamics, combustion, and heat transfer
    - Correlation-based mechanical friction characteristics
    - Complete actuator set, including VCT, charge motion control valve, etc.
  - Are easiest to implement in engine modeling tools such as GT-Power
    - GT-Power production engine models are available from Ford Engine Engineering Organization
    - Import to Simulink through S-Function feature

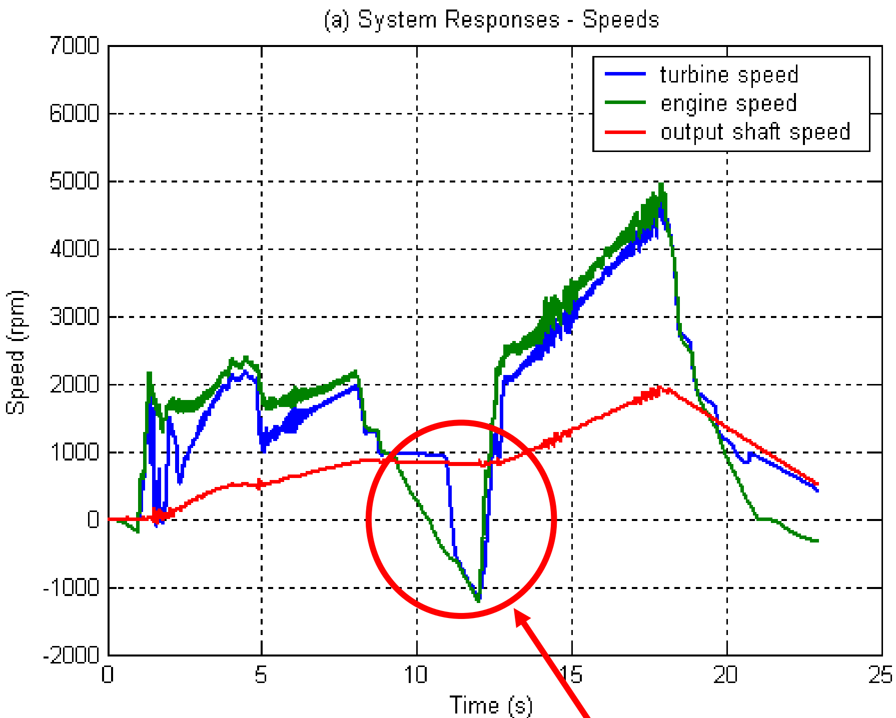
Engine Control Modeling

- Simplified representation is useful for most HEV applications with features including:
  - Idle speed control
  - Fuel injector control
  - Spark retard
  - Fuel cut-off
  - Target λ control
  - VCT control
  - Throttle control
- Full production engine strategy are needed in some limited cases. Difficulties encountered include:
  - Handling crank-based events
  - Resolving interfaces resulting from removal of low-level drivers
  - Resolving interfaces after removing features not needed for vehicle system functional modeling, such as diagnostics and fault-safe modes

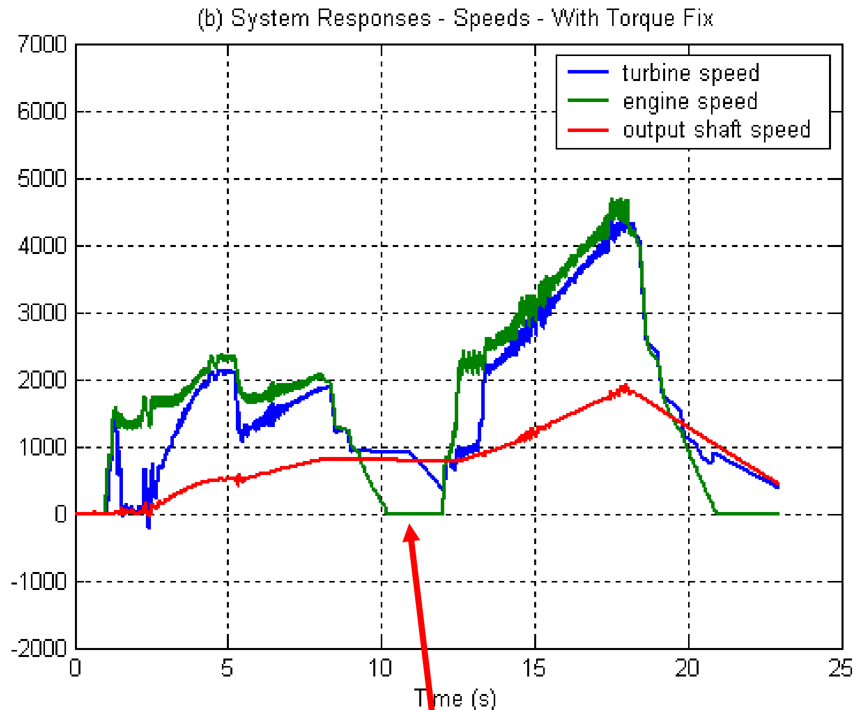
Engine Integration Issues

- Most models are not formulated to run at low engine speeds -- between 0 and 500 rpm
  - For mean-value models, add data points down to 0 rpm for tables and ensure that regressions behave appropriately down to 0 rpm
  - For crank-angle-based models, appropriate treatment of rubbing friction is necessary
- Proper treatment of engine deceleration after shut off
  - Logic can be added to the engine plant to produce zero torque when the engine reaches 0 rpm
  - A limit of 0 rpm can be set on the engine speed integration

Engine Deceleration After Shut-Off



Engine Continues to spin down to negative RPM after engine shut-off

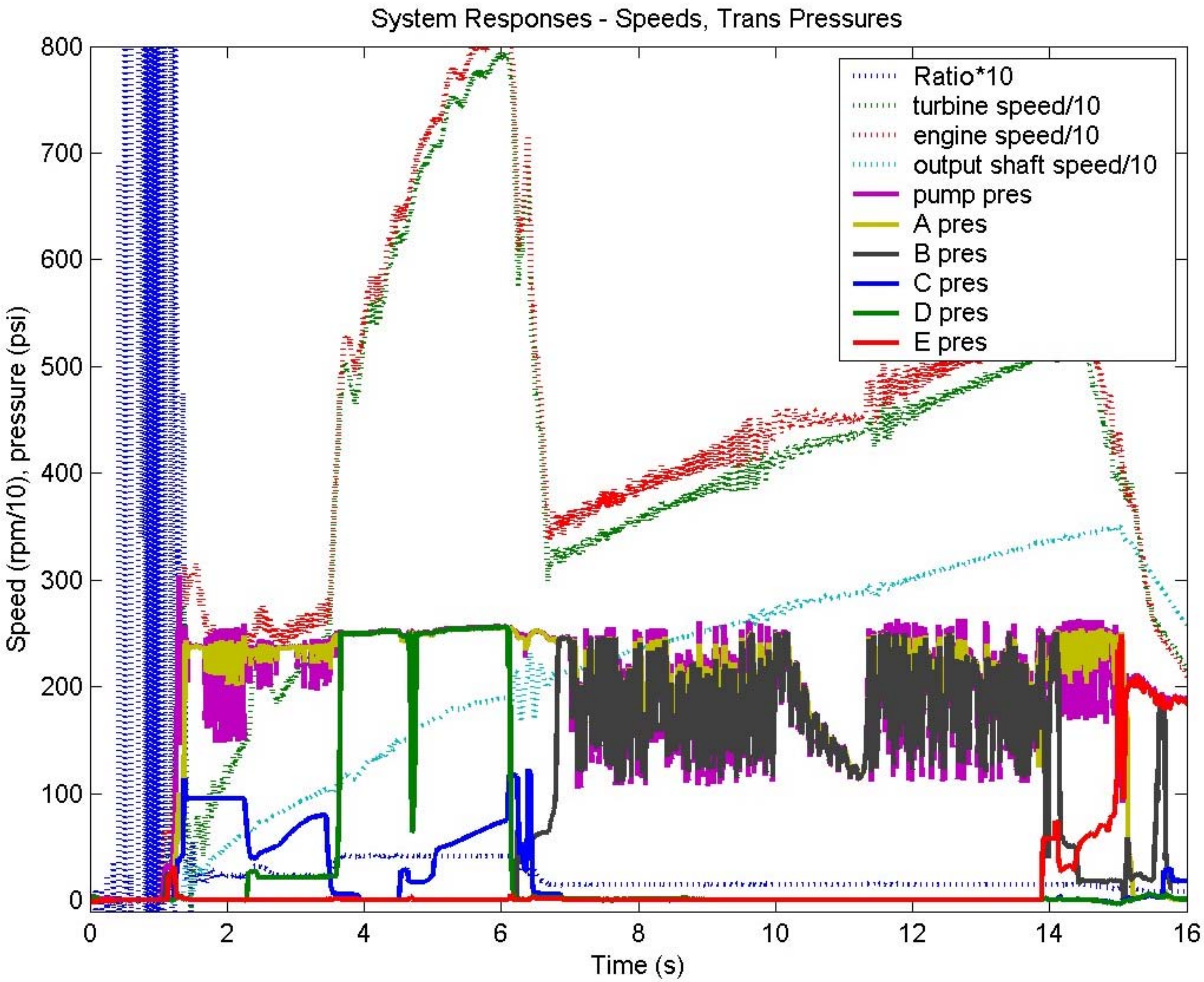


Engine behavior corrected after fixes

Transmission Modeling

- Plant
  - Mechanical dynamics modeled at component level: gear sets (planetary, Ravigneaux, bevel, etc.), clutches (plate, band, and one way), torque converters
  - Various modeling tools used within Ford: Native Simulink, AMESim, Dymola, proprietary Ford Transmission Simulation Environment (FTSE)
- Control representation can be:
  - Simplified basic algorithms, such as boost, torque transfer, inertia transfer, and final ramp-up phases of a shift.
  - Full production strategy can be implemented for selected applications.
    - Requires hydraulic subsystem model from FTSE tool

Transmission Simulation Results

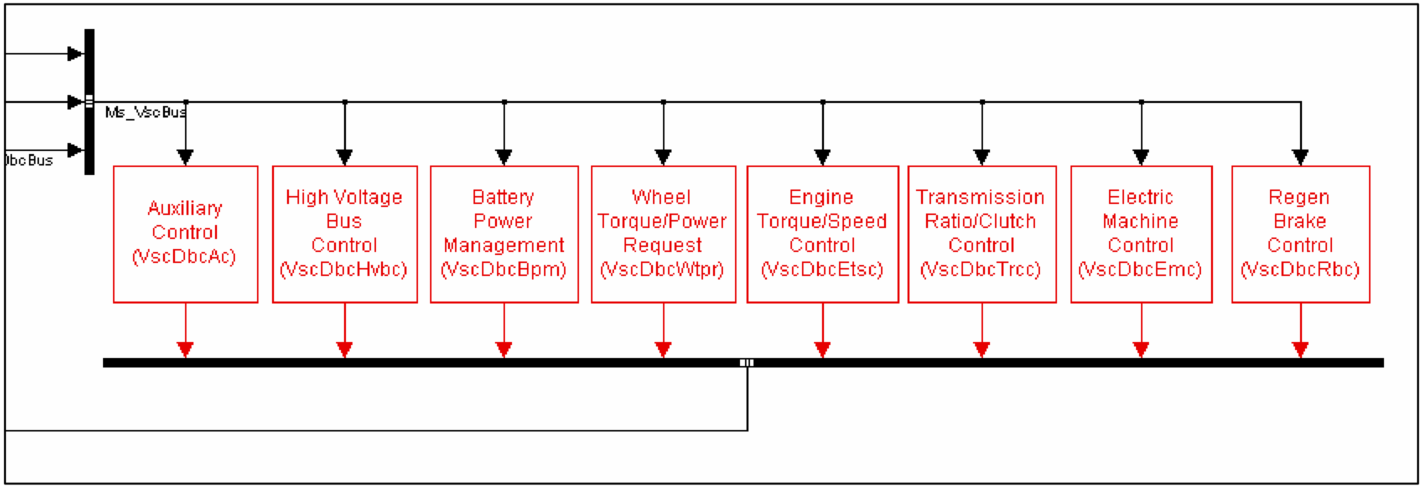


Transmission Integration Issues

- MATLAB version compatibility issues for models integrated as Simulation S-Functions involve treatment of:
  - Mex build commands
  - Compiler options
- An automated process needed to be created to integrate Dymola models
- Special customized tool needed to incorporate transmission control codes into the model

Vehicle System Control

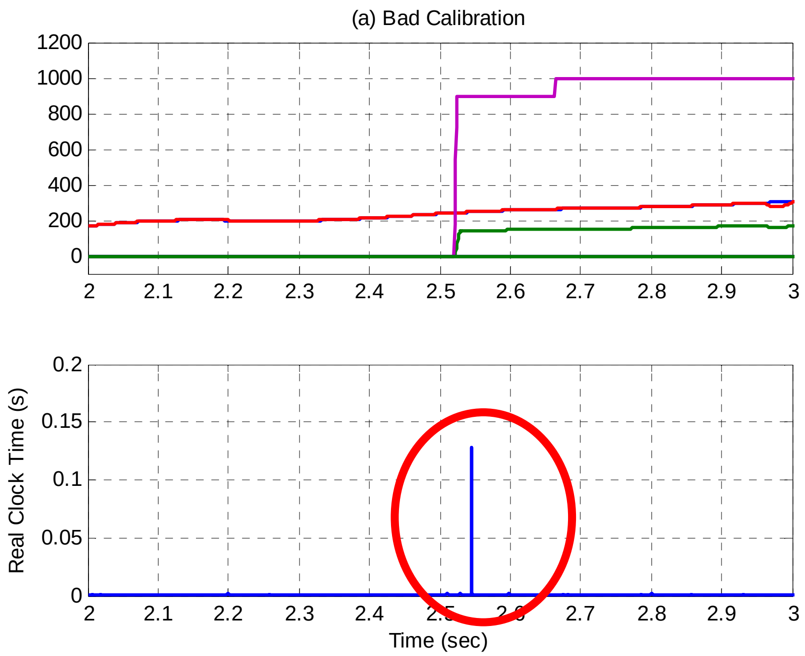
- General features related to HEV VSC include:
  - Engine stop/start
  - Regenerative braking
  - Battery energy management
  - Driver demand evaluation

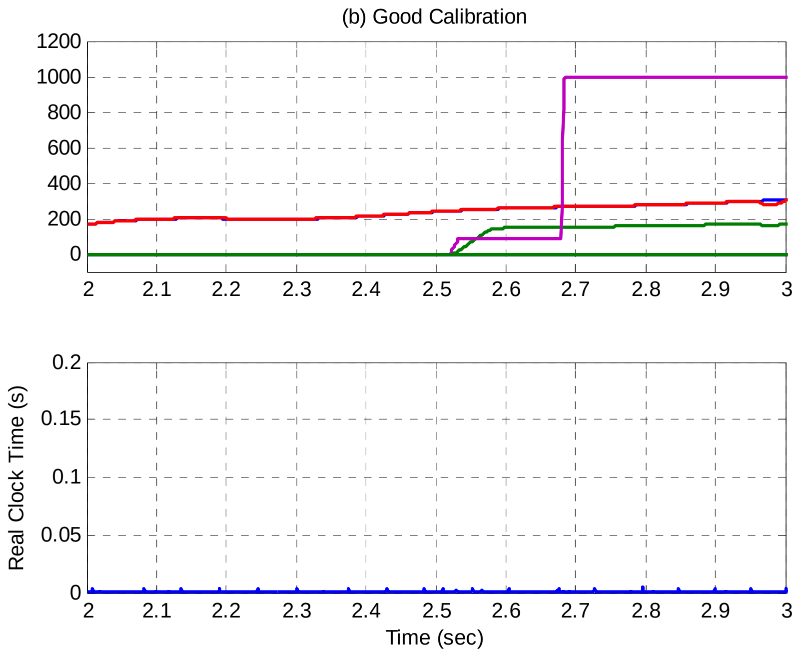


Real-Time Simulation

- For select applications, e.g. HIL, models must run in real-time
- Diagnostics tools are needed to identify the computational bottlenecks in tools including:
  - Native Simulink - good diagnosis tools such as Model Profiler and Model Advisor
  - S-functions - Native diagnostic tools:
    - Only identify which S-Functions consume the most computational time
    - Don't provide information about the internal S-Function behavior that causes the problem
  - Customized diagnostic tool for Simulink - developed at Ford to identify the time-consuming parts of an S-Function submodel

Real-Time Simulation





Spike occurred in Real-Time Simulation

After Real-Time Diagnostic Tool, Spike has been eliminated

Conclusions

- Numerous challenges exist with integrating models from various sources to create robust vehicle system models
- Standard modeling practices and rigorous model specifications reduce integration efforts
- A process for creating complex vehicle system models has been developed for HEV applications and a knowledge base has been established for Model-Based System Engineering
- Critical needs remain:
  - Enhance modeling standards for tool sets beyond Simulink and Stateflow®
  - Tools and methods for rapid development of model requirements and specifications
  - Automated test and verification
  - Enablers for rapid upgrade to new versions of modeling tools and environments
  - Better diagnostic tools to reduce debugging time